TOUGH2 AS A TOOL FOR PERFORMANCE PREDICTION OF THE BALCOVA GEOTHERMAL FIELD, TURKEY

Goker Ertunc, Mahmut Parlaktuna

Middle East Technical University (METU)
Department of Petroleum and Natural Gas Engineering
Ankara, 06800, TURKEY
e-mail: egoker@metu.edu.tr

ABSTRACT

The Balcova geothermal field, located in the Izmir Bay area of the Aegean coast of Turkey, is the first field utilized in Turkey for direct heat application. Today, the total residential area being heated by the produced water is around 2,470,000 m^2. The produced water with a temperature range of 100–140°C has low dissolved solids and noncondensable gas content. The field has production characteristics of 1800 m^3/hour at peak times of the heating period and about 300 m^3/hour during summer months, when water is needed for balneology. On average, 85% of the produced fluid is re-injected after its energy is taken into heating centers. The field currently has 11 production, 6 re-injection and 4 observation wells.

We recently constructed a three-dimensional numerical simulation model of the field using the TOUGH2 software. A natural-state model was established based on the conceptual model of the field and further calibrated by the available production/injection data, recorded pressure-temperature values from production wells and water level measurements from observation wells for 1996–2012. Future performance of the field was discussed after forecasting runs. Results show that production could be sustained for the next 15 years with the existing production/injection scheme.

INTRODUCTION

Balcova Geothermal Field, the first field utilized in Turkey for direct heat application, is located in the Izmir Bay area of the Aegean coast, 11 km southwest of the city of Izmir (Figure 1).

Figure 1. Location map of the Balcova geothermal field (Aksoy & Filiz, 2001).

The construction of the Balcova district geothermal district heating system was started in 1996; today, the system is the biggest district heating application in Turkey with heating capacity of 159 MW_t heating an area of 2,470,000 m^2. The hot-water production rate of the field is 1800 m^3/hour at peak times of the heating period, and the field has a theoretical production capacity of 2050 m^3/hour, if all the production wells were put into production (Ozdiler & Sayik, 2011).

There has been a continual increase in demand for space-heating applications in the Balcova area. As a result, both produced and injected volumes of geothermal water for heating have been increasing. Large production and injection practices in any geothermal field must be carefully with respect to not harming the reservoir characteristics of the field, such as avoiding a decline in reservoir pressure due to high production without sufficient injection, or avoiding a decline in temperature due to excess injection and early breakthrough.

This study is aimed at constructing a reservoir simulation model for the Balcova Geothermal Field, to help in making performance predictions that could guide us in future field operations.

CONCEPTUAL MODEL

Reservoir simulation starts with the construction of a detailed conceptual model, in which existing field data are evaluated carefully and important physical and chemical processes that influence the system are identified. The conceptual model defines a grid-free representation of all the properties that are used to describe the geothermal system. These are generally flow boundaries, alteration, main geologic features such as faults and layers.

The extensive fracture system that developed in the Balcova area within the Izmir Flysch sequence created a convective hydrothermal system. The geothermal system in Balcova is fed by meteoric water that infiltrates down through faults, joints and fractures (pointing to the NW, N and NE) into the Izmir Flysch, attaining deep levels (at least 2000 m). Deep circulating waters are heated by an unidentified heat source, and then ascend through the Agamemnon Fault. Uprising geothermal fluids change flow laterally to the north through two main highly fractured zones, acting as outflow zones of the geothermal system. These zones are situated at 40 - 100 m and 300 - 1000 m depths. At present, both the hot water in the shallow alluvium, and the hot water in the deeper outflow zone are used (Serpen, 2004). To date, around 50 wells, with depths ranging from 45 m to 1100 m, have been drilled in the Balcova area. Some of these wells have been abandoned because of technical difficulties. The field currently has 11 production, 6 re-injection and 4 observation wells. Figure 2 illustrates the hydrogeological conceptual model and also well locations of the Balcova geothermal field.

DEVELOPMENT OF THE NUMERICAL MODEL

The purpose of developing a numerical model is to match the static and dynamic temperatures and pressures of the system and reproduce all the significant features of the conceptual model. In this study, TOUGH2 (Pruess et al., 1999), a numerical simulation program designed for multi-dimensional fluid and heat flows of multiphase, multi component fluid mixtures in porous and fractured media, was used to develop the numerical model.

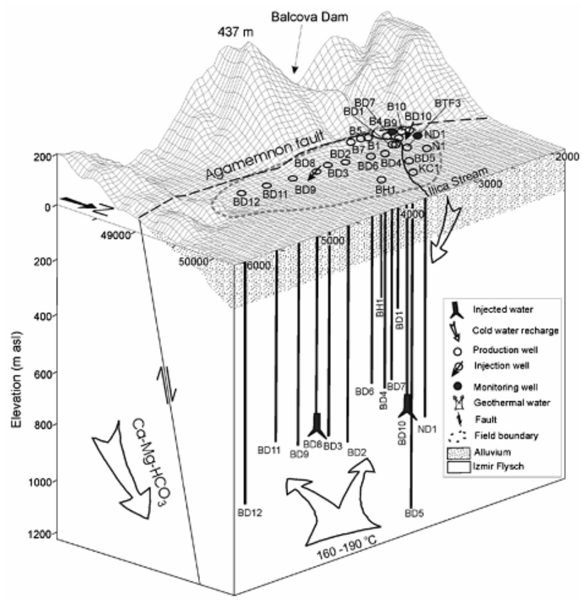

Figure 2. Conceptual model of the Balcova geothermal field (Aksoy et al., 2007).

A total of 45,696 grid blocks were used to define the geothermal system in Balcova; overall dimensions of the model are 3200 m × 1600 m × 2550 m in x, y and z directions, respectively. Thus, total volume is around 13.2 km^3. The model consists of 26 layers, with thicknesses ranging from 5 m to 400 m. By using small thicknesses, it is possible to separate different formations, permeable and impermeable zones at nearly exact depths. Figures 3 and 4 show the top and elevation views of the three-dimensional model constructed.

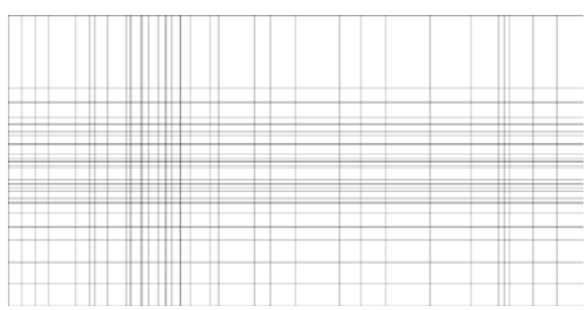

Figure 3. Top view of the three-dimensional model.

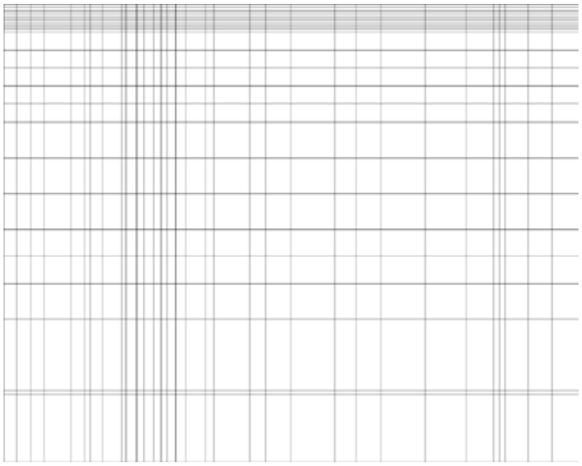

Figure 4. Elevation view of the three-dimensional model.

The numerical model was then calibrated in two stages, first by matching the natural state of the reservoir, and then by matching the production/injection history of the field.

NATURAL-STATE MODELING

Natural-state modeling is the stage of geothermal reservoir modeling in which the state of the field before its exploitation is modeled. It is known that geothermal reservoirs evolve over geological time. The rate of change in thermodynamic properties during geological time is minimal compared to changes resulted from exploitation of the reservoir. Thus, the geothermal reservoirs in their natural state can be considered in pseudo-steady state conditions. It is a common practice in geothermal reservoir simulation studies to run the model without any production/injection conditions to reach the pseudo-steady state (Bodvarsson et al., 1986).

The natural state model was developed using trial and error procedures until the calculated temperatures reasonably matched the measured temperatures. Permeability values were adjusted until a good match was obtained. Also, the natural influx was specified as a rate of 50 kg/s with an enthalpy of 6.6E5 J/kg at the base of the Agamemnon Fault.

Figures 5 and 6 compare the measured and model temperature profiles of shallow B-10 well and deep BD-2 well, respectively. In both wells, the measured and model temperature values are in good agreement.

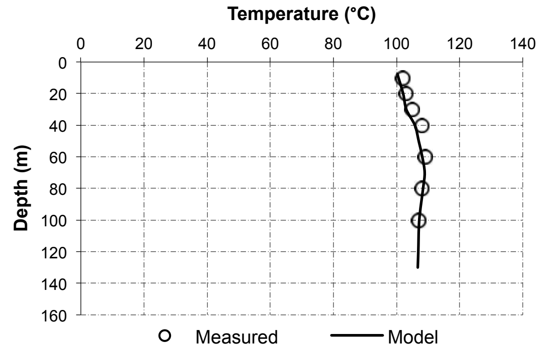

Figure 5. Temperature vs. depth profiles of the shallow B-10 well.

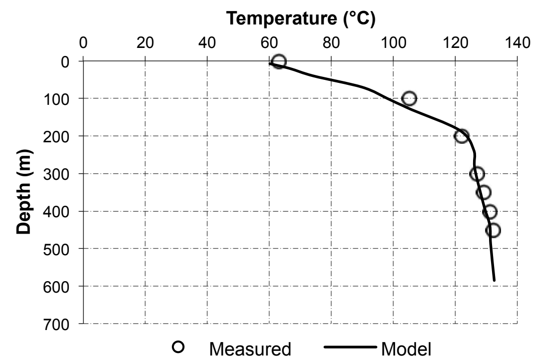

Figure 6. Temperature vs. depth profiles of the deep BD-2 well.

HISTORY MATCHING

A second matching stage of calibration has been carried out for systems having some production history. The history-matching process involves numerous iterations and parameter adjustments until a reasonable agreement is obtained with the time-dependent production history (Bodvarsson, 1988).

Using the temperature and pressure values obtained from the natural state modeling and production/injection data recorded between years 1996 and 2012, we conducted a simulation of the exploitation period for 16 years. After making several adjustments to the model, we arrived at a reasonable match to the measured data.

Bottom-hole temperature values obtained from the simulation study were matched with the values measured during the period 1996–2012. Figures 7 and 8 show the simulated (model) temperature values compared with the measured temperature values for the shallow B-10 well and deep BD-2 well, respectively. As can be seen in the figure, both data sets are in good agreement.

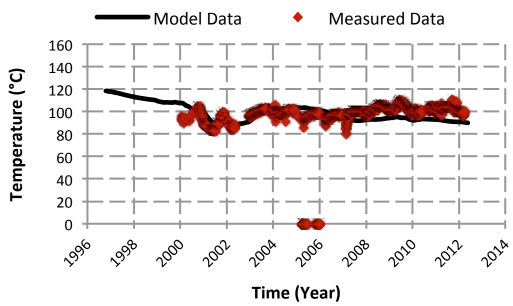

Figure 7. A comparison of simulated (model) and measured temperatures for the shallow B-10 well.

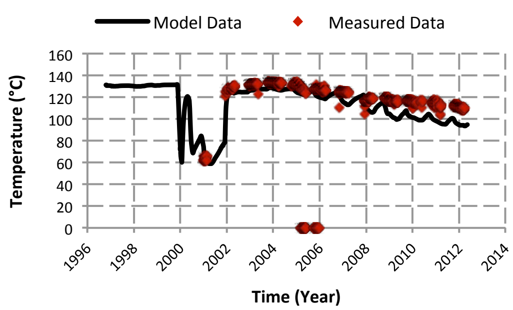

Figure 8. A comparison of simulated (model) and measured temperatures for the deep BD-2 well.

Since there are no recorded bottomhole pressure values for production wells, measured water level data obtained from the observation wells were matched with the simulated pressure values. Again, the model data reasonably matched the measured water level data.

FUTURE PERFORMANCE PREDICTIONS

After successfully calibrating the model by natural-state modeling and history matching, we then used it to predict the future performance of the field. The forecasting run, which covered a period of 15 years, assumed that the production and injection history for the entire field as of January 2012 would be maintained for the next 15 years. For initial conditions, temperature and pressure values obtained at the end of the history matching stage were used.

The results of the forecasting run show that the temperature values could not reach their original values at the end of each year. The decline in simulated bottom-hole temperature values at wells B-10 and BD-2 is illustrated on Figures 9 and 10, respectively.

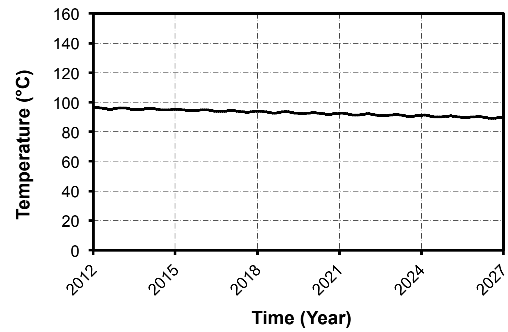

Figure 9. Simulated bottomhole temperature profile of the shallow B-10 well.

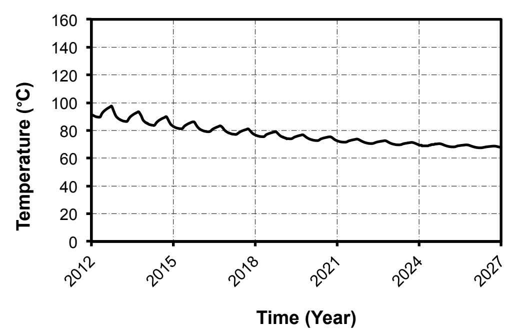

Figure 10. Simulated bottomhole temperature profile of the deep BD-2 well.

On the other hand, as seen in Figure 11, the bottom-hole pressure of the shallow B-10 well declines ~2 MPa in winter (at peak times of the heating period) and recovers to its original value in summer due to natural recharge. The pressure trend in the deep wells is also similar. A pressure drawdown of ~1 MPa is observed from winter to summer months in the deep BD-2 well (Figure 12).

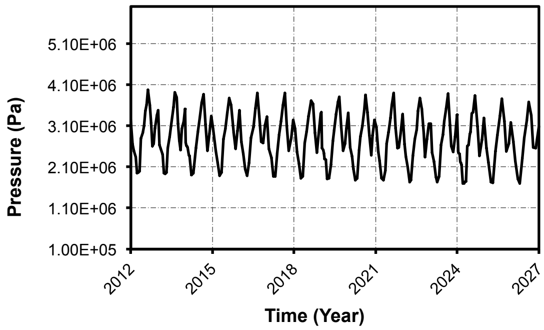

Figure 11. Simulated bottomhole pressure profile of the shallow B-10 well.

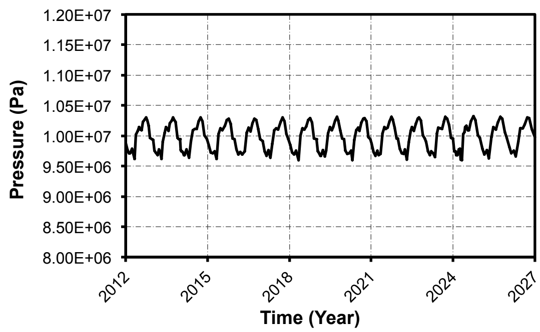

Figure 12. Simulated bottomhole pressure profile of the deep BD-2 well.

CONCLUSIONS

A numerical model of the Balcova geothermal field was constructed. The numerical model was then calibrated in two stages, first by matching the natural state of the reservoir, and then by matching the production history of the field.

The natural state modeling of the field reasonably matched with the available bottomhole temperature and pressure data from existing wells in the field. The model was then calibrated against the available production/injection data with reasonable matches being obtained to the temperature and pressure of the reservoir. Thus, the obtained model provides a good representation of the field, which could be used for predicting the response of the field exploitation.

The results from the forecasting run, which covered a period of 15 years, indicate that the Balcova Geothermal Field is sustainable for the next 15 years with the existing production/injection scheme.

REFERENCES

Bodvarsson, G., Pruess, K., & Lippmann, M. *Modeling of Geothermal Systems*. Journal of Petroleum Technology, 1007-1021, 1986.

Bodvarsson, G., *Numerical modeling of geothermal systems with applications to Krafla, Iceland and Olkaria, Kenya*, Lawrence Berkeley National Laboratory Report 23950, 1988.

Pruess, K., Oldenburg, C., Moridis, G., *TOUGH2 User's Guide, Version 2.0*, Berkeley University Press, California, 1999.

Aksoy, N., Filiz, S., *Investigation of Balcova-Narlıdere Geothermal Field by Isotopes*, Proceedings, 1st Environment and Geology Symposium (ÇEVJEO'2001), Izmir, 21-23 March, 2001.

Serpen, U., *Hydrogeological investigations on Balçova geothermal system in Turkey*. Geothermics , 33, 309-335, 2004.

Aksoy, N., Serpen, U., Filiz, S., *Management of the Balcova-Narlidere geothermal reservoir*, Geothermics, Turkey, 2007.

Ozdiler, U., & Sayik, T., *Balçova - Narlidere Jeotermal Saha İşletmesi*. X. Ulusal Tesisat Mühendisliği Kongresi, 219-240, Izmir, 2011.